

Marine Gravity Storage

Rosenberg Semyon Ph.D., Lod, Israel, Ecological Imperative Scientific and Technical Association, Netanya Branch of Israel Independent Academy for the Development of Science
Email: semyon.rozenberg@gmail.com, tel. + (972) 524854666

Feinberg Vladimir Ph.D. Jerusalem, Israel, Netanya Branch of the Israel Independent Academy for the Development of Science E-mail: faynbergv@yahoo.com tel. : + (972) 72543027456

Annotation

The authors propose to build a Marine Gravity Storage (MGS). Another project among other projects of gravitational storage. The proposed MGN, unlike well-known projects, can store energy for hours, days and even months. Another project among other projects of gravitational storage, which has a high energy storage density and is much cheaper than known projects. The proposed MGS is built on a large pontoon anchored in the sea. In the energy storage mode, the load is lifted by the motor-generator, and in the generator mode, the load is lowered and received electricity.

The proposed MGS will have the following features:

- MGS do not require specially designated land-based economic areas.
- Modular design - stored energy of one module is 22 kWh, power in motor mode is 18 kW. The depth of the sea is 1 km or more.
- The territorial density of the stored energy from each 1 m² of the deck area is 11 kWh / m² and 11 GWh / km² of the area of sea.
- MGS can also be seasonal, which accumulate energy in the summer half of the year and release it in the winter half of the year. During storage, the load hangs in the upper position fixed by the ratchet and cannot lose energy.

In the fairly near future, renewable energy will make up a significant share of electricity generation. MGN as the cheapest storage complex are the most effective especially for renewable energy and will remove many obstacles limiting the widespread development of renewable energy.

The status quo

Energy consumption in the electricity network continuously changes during the day - maximum during the day, minimum at night. Solar and wind power stations also have a variable output per day.

Until 2013, in the United States, energy consumption by pumping occurred mainly at night. However, in recent years, pumping in the daytime has expanded significantly, and in 2016 and 2017 it surpassed pumping in the night. Solar and wind energy stored in the daytime is now used to meet the significant increase requirements caused by the sharp increase in net payload that occurs when solar or wind energy production drops.[1]

Various projects of Gravitational Energy Storages, considered in the media, provide for the construction of either towers or mines (including the use of abandoned ones). A tower or a mine

requires a large economic territory of the country and high costs for the construction of these capital structures.

The entire world scientific and technical community is frantically looking for efficient energy storage, millions of dollars are invested in research. [10] Further mass development of renewable energy is simply impossible without acceptable powerful storage devices. All known energy storage systems (electric batteries, hydrogen and ammonia systems, etc.) are still too "raw", expensive and cumbersome.

Many companies are working intensively to improve existing storage devices and research new directions. In particular, there are several projects of Gravitational Energy Storage. Below is considered another project in a number of other projects of gravitational storage. The proposed MGS's are the most efficient for weekly and seasonal renewable energy storage and will remove many of the obstacles limiting the widespread development of renewable energy.

Description of the offer

It is proposed to build several MGSs, united on one large pontoon. Pontoons can be placed in the sea, where the depth is 1 km or more.

In Fig. 1, for example, shows a diagram of MGS modules.

Legend in Fig. 1:

1- lower farm of pontoons, 2- cargo, 3- synthetic rope of cargo, 4- pontoon of module, 5- sea level, 6- deck of a large pontoon, 7- support stands, 8- drum, 9- gear of drum, 10- pinion on motor-generator, 11- motor generator.

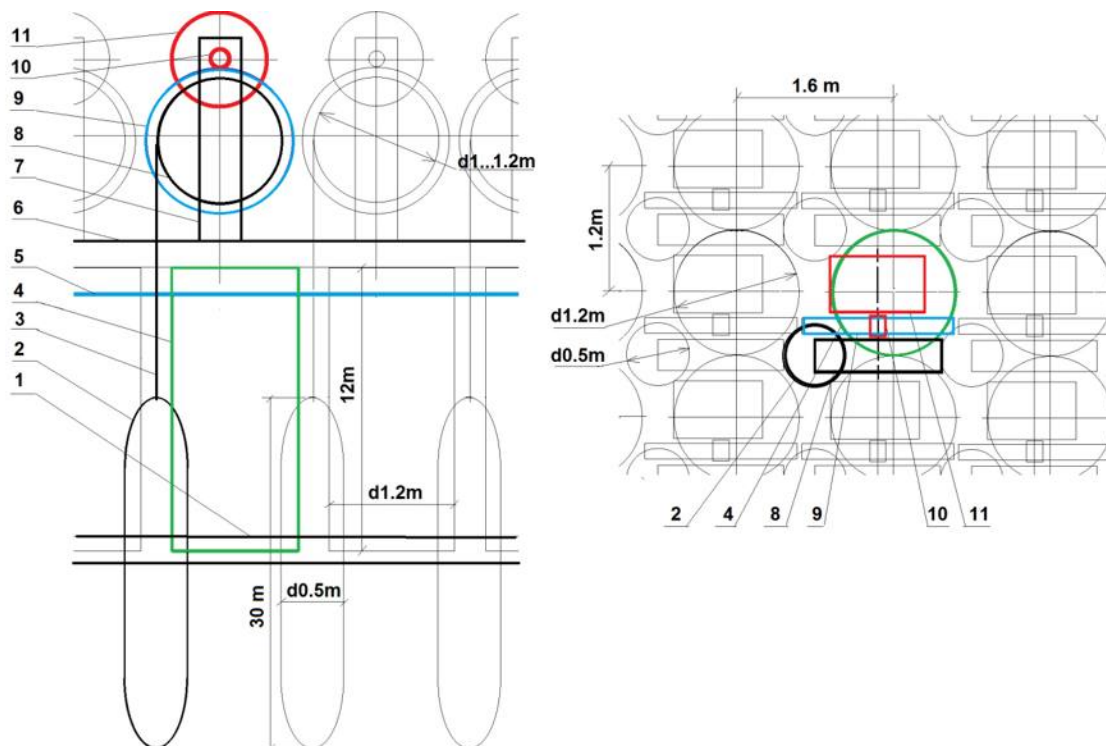


Fig. 1

The marine gravity storage unit consists of separate independent modules. MGS has a common deck 6 and a lower truss 1, between which there are pontoons 4. Pontoons protrude on 1 ... 2 m

above sea level 5. Above each pontoon 4 on deck 6 on support legs 7, the following devices and mechanisms are installed: drum 8 (shown in black), on the shaft of which we have a large gear 9 (shown in blue). The drum gear 9 is in engagement with the gear of the motor-generator 10 (shown in red), the shaft of which is connected to the rotor of the motor-generator 11 (shown in red). Motor-generator 11 is a reversible low-speed multi-pole electric machine with permanent magnets, which is electronically controlled. A synthetic rope 3 is wound on the drum 8. The rope has a diameter of 12 mm and a breaking force of 13,900 kg, the working load is taken as 8,000 kg. Weight 2 is attached to rope 3. There are brake mechanisms on the shafts of the motor or drum, for example, ratchet - not shown in the figures.

All pontoons 4 - pipes together with the lower truss 1 and deck 6 form the frame of a large pontoon. The size of a large pontoon should be sufficient for the stable behavior of the pontoon at sea as a marine floating structure, for example, 60 m by 100 m. The large pontoon accommodates premises for various equipment and personnel, as well as a crane or telfer for mounting and dismantling modules. The pontoon is connected to the shore by an electric cable to receive and return electricity. The large pontoon has anchors.

In the upper position, the cargo is held by the brake mechanisms, and the energy is stored in the module. The cargo on the ratchet can hang for an unlimited time - an hour, a day, year. To return the energy, the brakes are released, the cargo is lowered and the generator rotor is rotated through the rope, the drum and gears. The speed of lowering the load is taken as 0.2 m / s and is electrically controlled by the generator load. In the lower position, the cargo is also held by the brakes. The speed of 0.2 m / s is chosen to reduce friction losses when moving the load and rope in the water. The accumulation of energy takes place. when the cargo is lifted by the motor to the upper position. The lifting speed is also 0.2 m / s. The duration of both ascent and descent is 1.4 hours ($5000 \text{ s} = 1000 \text{ m} / 0.2 \text{ m} / \text{s}$).

Calculation of the MGS module

-In the MGS device under consideration, all devices are widely used: drum winches and gear drives for hundreds of years, inverted electric machines on permanent magnets for tens of years.

- The main knot that determines all the characteristics of the module and its efficiency is a synthetic rope on which the load is suspended. We propose to use as a rope a rope made of ultra-high molecular weight polyethylene (UHMWPE) made of synthetic fiber ALL-TOP SPECIFIC STANDARD with a diameter of 12 mm, which has a tensile strength of 31,500 pounds (breaking force 13,900 kg, working load 8180 kg). [2]

- Let's take a nominal drum diameter of 1000 mm. Rope $\phi 12\text{mm}$, rope volume $1.2 * 1.2 * 100000 \text{ cm} = 144000 \text{ cm}^3 = 144 \text{ liters}$. The inner diameter of the coil of the cable on the drum is 100 cm, the outer diameter of the coil on the drum is 120 cm (provided that the cable is tightly laid), the width of the drum is 50 cm. The volume of the coil is $0.78 * (120^2 - 100^2) * 50 = 171 \text{ liters}$.

- The rope has buoyancy, therefore we neglect its mass.

The load must have a mass that creates a gravitational force in water of 8000 kgf.

- We apply concrete with a density of $2400 \text{ kg} / \text{m}^3$ for the manufacture of cargo, we obtain the volume of concrete cargo equal to $5.84 \text{ m}^3 (= 8000 / (2400 - 1030))$. The dimensions of the cargo are 0.5 m in diameter and 30 m in length, weight in the air - 14000 kg ($= 2400 * 5.84$). The cargo should have rounded streamlined butts to reduce hydraulic losses when moving in water.

- Pontoon is a plastic cylindrical pipe 1.2 m in diameter, 12 m in length, pontoon volume 13.5 m^3 . The pipe is sealed on both sides. We accept, that the displacement of each pontoon is equal

to 11000 kg: - cargo 8000 kg and 3000 kg - the mass of the structure's share (deck, lower truss, drum, etc.), per one pontoon. The deck of a large pontoon is 1 ... 2 m above sea level.

- We have a drum rotation speed of 3.2 rpm. ($= 60 * 0.2 / 1.2 * \pi$). The motor generator is a 3-phase reversible low-speed multi-pole permanent magnet electric machine with a rotation speed of, for example, 150 rpm. The gears have a diameter ratio of 1500 to 32 mm.
- The size of one module on the deck is 1.2 m by 1.6 m, the area on the deck is 1.9 m².

Energy balance

When calculating, we have for each module: the mass of the load creates a force of 8000 kg in sea water, we neglect the mass of the cable. In the upper position of the load, only the weight of the load 8000 kg acts on the drum (creates a torque). Height difference - cargo travel $H=1000$ m.

The accumulated energy E is:

$$E [J] = g * M [kg] H [m]. E [kWh] = g * M [kg] H [m] / 1000 * 3600.$$

$$E = 9.81 * 8000 * 1000 / 1000 * 3600 = 22 \text{ kWh}.$$

The consumed and returned energy is determined by the efficiency of electrical conversions 0.95 and the efficiency of mechanisms. The efficiency of the gear train is 0.98, the efficiency of the drum and tape is probably close to the efficiency of the conventional gear train of 0.98. We take the speed of the cargo to be no more than 0.2 m / s to reduce hydraulic losses when the cargo and tape move in water. Let's take efficiency = 0.96. The total efficiency will be $k = 0.87$.

The received energy from the network, from a solar or wind power plant in the mode of lifting a load in the motor mode is $E_m = E / k = 22 / 0.87 = 25 \text{ kWh}$. The delivered energy in the generator mode: $E_g = E * k = 22 \text{ kWh} * 0.87 = 19 \text{ kWh}$. The motor power with a lifting time of 1.4 hours will be $P_m = E_m / t = 25 / 1.4 = 18 \text{ kW}$. The power of the generator with a lowering time of 1.4 hours will be $P_g = E_g / t = 13.6 \text{ kW} (= 19 / 1.4)$.

The power for lifting or lowering is changed by electrical control. Since we have several modules working together, several modules work in an optimal mode, one in a partial mode, the rest stand.

Profitability

The profitability of MGS is formed from 2 sources - in the power grid of the country and at the owner of MGS.

Savings are generated in the country's power grid:

- from reducing the consumption of fossil fuels,
- from reducing capital costs for conventional power plants,
- from reduced operating costs at conventional stations,
- from reduced costs associated with air pollution caused by electricity generation,
- from reducing greenhouse gas emissions.

Directly the owner of MGS receives some share of the above-mentioned savings in the network, and also receives the difference between the cost of the energy purchased and sold to the network.

There are three possible modes of using the energy accumulated in the MGS.

- The first mode is the mode of daily energy storage, when the power of renewable energy sources is less than the power consumed by consumers from the network. Solar photovoltaic power plants in the sundial and wind farms sell all the generated energy to the grid. At the same time, MGS operates in a daily energy storage mode and interacts only with the country's power grid. In the evening MGS buys energy at the evening rate. And during rush hours MGS sells the

stored energy to the grid at the peak tariff. Nightly electricity rates are lower than daily rates. The difference in costs will make the savings, which will be the greater, the more MGS modules are built.

- The second mode is also a mode of daily energy storage, but when the capacity of renewable energy sources in the country began to exceed the power consumed by consumers from the grid. Solar photovoltaic power plants in the sundial and wind farms also sell all the generated energy to the grid. But in this mode, the MGS during peak hours, on the contrary, receive and accumulate this excess energy from renewable sources. And in the evening MGS returns the accumulated energy to the country's power grid. The income from the energy accumulated during peak hours will be the more, the more MGS modules are built. And the more MGS modules are built, the more the share can be of renewable energy in the country's energy sector.
- The third mode: MGS can also be seasonal storage devices, which accumulate energy in the summer half of the year and release it in the winter half of the year. This is very important for large-scale use of solar power plants, because solar panels on the "most" winter day generate energy 3 times less (at the latitude of Israel) than on the "most" summer day.

Economic efficiency

The economic efficiency of MGS depends on the cost of materials and labor costs for construction.

The cost of some materials and labor costs for 1 module is:

- The cost of concrete. The volume of cargo is 6 m^3 , the price of concrete is $4000 \text{ rubles} / \text{m}^3 = 50 \$ / \text{m}^3$, the cost of concrete is $50 * 6 = \$300$. [3]
- The cost of steel pipes for the frame: diameter 100 mm, thickness 4 mm, length 10 m is $100 * 4 * 10 * 2 = 8000 \text{ rubles} = \$100$. [4]
- The cost of the pipe for the pontoon: PE 100 SDR33 1200mm 12 m, price for 12 m 15000 rubles, cost 15000 rubles = \$200 [5]
- The cost of manufacturing the frame of the structure will be equal to the cost of the frame pipes and pontoons: $100 + 200 = \$300$.
- The cost of a synthetic rope for an ALL-TOP winch: 1/2 inch is \$1.58 USD / ft, the cost of 1000 m is $1.58 * 1000 / 0.32 = \$5.000$. [2]
- Cost of drum and gear winch. Price 5000 rubles / t, $8t * 5000 = 40000 \text{ rubles} = \$500$ [6]
- The cost of the motor-generator is 20 kW, 40000 rubles = \$500 [7].
- The cost of electrical equipment for controlling the motor-generator will be equal to the cost of the motor-generator \$500.
- The total cost of some materials, labor and equipment will be $300+100+200+300+5000+300+500+500=\$7200$.

The economic efficiency of energy storage can be of the order of $330 \$ / \text{kWh}$ ($= 7200 / 22$). The cost of the cable accounts for almost 70% of the cost of the entire module. As the scale of construction of modules increases, it can be assumed that the cost of the cable will fall and new, more durable materials will be used, and therefore the economic efficiency will undoubtedly improve. On a large pontoon $60 \times 100 \text{ m}$ we have 3000 modules ($= 60 * 100/2$), which can store 66,000 kWh of energy completely without losses for hours, weeks or months. The possibility of weekly and seasonal energy storage of 66 MWh on a pontoon is a unique advantage of the proposed module over all other known energy storage devices.

The size of one module is 1.2 m by 1.6 m, the area on the deck is about 1.9 m^2 . The territorial density of the stored energy will be $22 \text{ kWh} / 1.9 \text{ m}^2 = 11 \text{ kWh} / \text{m}^2$ of the deck area, i.e. 11

GWh / km² of the sea area. For example, the cost of materials and labor at the Gelboa PSP in Israel (2020) is \$ 200 / kWh (= NIS 2,000,000,000 / 3.3 * 3,000,000 kWh). [9] The area of both basins of the PSPP is 2 km², the territorial density of accumulated energy is 3,000,000 kWh / 2,000,000 m² = 1.5 kWh / m² of the territory of the basins, i.e. and the economic territory of the country.

Various projects of Gravitational Energy Storages, considered in the media, provide for the construction of either towers or mines (including the use of abandoned ones). For the proposed Marine Gravity Accumulator with a 8-ton cargo at sea, an area of about 2 m² per module is sufficient. A tower or mine with the same cargo will require a significantly larger economic territory of the country and significantly higher costs for the construction of these capital structures.

Conclusion

1. This proposal is extremely relevant. The entire world scientific and technical community is frantically looking for efficient energy storage, millions of dollars are invested in research. Further massive development of renewable energy is simply impossible without acceptable powerful storage devices. All studied energy storage systems (electric accumulators, hydrogen and ammonia systems, etc.) are still too "raw", expensive and cumbersome. All known energy storage systems (electric accumulators, hydrogen and ammonia systems, etc.) are still too "raw", expensive and cumbersome.
2. In the considered MGS all devices and equipment have been widely used already for tens and hundreds of years. The proposed MGS has a high territorial density of 11 GWh / km² of the sea area .
3. The proposed MGSs have a unique ability to be weekly and even seasonal accumulators of "green" energy.

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